Track It!
Enhancing GPS-Enabled Applications for Outdoor Sports and Activities

Henrique Malheiro

Instituto Superior Técnico

Abstract GPS devices are ubiquitous and widely used in outdoor sports and activities to collect positioning and fitness data. Nevertheless, a survey on state of the art applications shows that none of the existing applications support all the essential features required for a planning session. Thus, we developed a flexible, customisable, and extensible GPS-enabled application for visualising and planning outdoor sports and activities, with support for for digital mapping and the Portuguese Military Survey Maps. We also addressed planning algorithms such as grade calculation, climb detection and classification, variable pacing or track simplification. The solution was subject to usability tests in order to verify its effectiveness and results have shown that even inexperienced users are able to execute complex planning tasks. We found the climb detection and classification algorithms to be flexible and accurate, and to produce reliable results when compared with cycling races data. The track simplification algorithm proved to be effective in preserving track shape and maintaining an higher track point density on climb segments.

1 Introduction

In recent years a number of GPS-enabled applications for outdoor sports and activities have emerged, becoming popular among athletes, coaches and outdoor activities enthusiasts. Two main reasons have contributed to this sudden interest in this type of applications.

On the one hand, the availability to the general public of affordable, sturdy, precise, and full-fledged GPS devices made possible the collection of large quantities of raw data and opened up a whole new range of possibilities, but demanded, at the same time, the existence of additional tools to extract meaning from the data. On the other hand, dedicated GPS devices are slowly stepping aside to give place to mobile phones and smartphones, equipped with GPS chips that made the use of GPS data even more ubiquitous. Besides, these devices rely on other features that give them an edge over dedicated devices, in particular processing power, internet connection, assisted GPS, bluetooth connectivity, accelerometers, integrated cameras, as well as support for commercial and community applications, which opens up the path for improvements, opportunities and innovation.

Driven by those two trends, in particular GPS devices and digital maps, GPS-enabled applications have evolved from platform-specific desktop applications to web applications and, more recently to mobile applications. They started to be distributed, often freely, by vendors whenever a customer bought a GPS device, but soon several commercial solutions and community projects began to emerge.

Activity planning assumes particular relevance nowadays. By planning we mean all the tasks involved in defining a route, calculating summary data, setting a pace, and annotating the track with all the relevant information for performing the activity. Despite the large number of GPS-enabled applications available on the market and increased sophistication, the available software generally lack flexibility as it is often platform-dependent, require a working internet connection, and seldom provide extensibility mechanisms to enhance current features and/or add new features. Moreover, some of the algorithms which are successfully applied to visualization and performance analysis could be very useful to assist planning tasks. Grade calculation, for example, may be of great value to detect and classify climbs and descents and annotate activities with detailed information about them. Grade data may also be used to establish a variable pace which improves estimates on the activity time, not only while planning but also during the activity, besides providing useful information to real time assessment of performance. Track simplification is another key feature to reduce the required resources and increase the performance of GPS devices while ensuring crucial information is delivered on time.

1.1 Goals and Research Topics

Driven by the motivations just depicted, we aimed to achieve the following goals:

1. Develop a flexible, customizable and extensible GPS-enabled application for visualizing and planning outdoor sports and activities;
2. Give support to the most popular mapping providers available online and seamlessly integrate the Portuguese Military Maps;
3. Study useful algorithms for planning activities, namely grade calculation and its applications to climb detection and classification, variable pacing or track simplification.

Developing a GPS-enabled application for visualizing and planning activities which is simultaneously flexible, customizable and extensible is in itself quite a demanding task. Several issues have to be addressed namely 1) choosing an adequate data model; 2) carefully designing an architecture which allows multiple synchronized views over the same data, as well as the addition of new modules; 3) including import and export capabilities for the most popular data formats and allowing the addition of new formats later on; 4) supporting several non-functional requirements like platform independence, off-line operation, localization and preferences.

2 Survey on State of the Art GPS Applications

In this section we present the results of the survey on state of the art GPS applications, with focus on the research questions we have identified. It is our purpose to summarize what can and cannot be done with existing software and identify its limitations, so we can contextualize current work and demonstrate its relevance. Six categories of problems were considered: a) track editing capabilities; b) map providers; c) grade calculation; d) climb detection and classification; e) pacing; and f) track simplification. Target applications were selected based on functionality, availability, popularity, relevance, and supported platforms. The surveyed applications included: a) Bike Route Toaster [1]; b) Map My Ride [2]; c) GPSies [3]; d) Strava [4]; e) Sport Tracks [5]; f) Adze [6].

Planning activities requires most of the time creating routes from scratch or manipulating existent tracks. In this survey we found that there is good support for mapping tracks either using the routing algorithms supplied by existing map providers or drawn point by point. There are also some useful options to assist these tasks like elevation fetching or signalling the most popular or competitive track segments. Nevertheless, advanced track manipulation, including combining existing tracks, is seldom supported.

We also found that only a few route planning applications offer the possibility to mark tracks with relevant information to be used while performing the activities, and most of the time course points or waypoints must be manually added by the user. The exceptions are marking turns when using the provided routing algorithms, despite the fact that this is only useful for mapping activities that follow roads. Inferring turns from bearing often result in inaccurate information.

Google Maps, Bing Maps or Open Street Maps are the most common choices when it comes to digital mapping support. Only a few applications support more than two map providers and even less add extra functionality such as hill shading or 3D views. There is some support to proprietary maps like Garmin maps, and from the reviewed solutions only Google Earth support custom maps, which have to be calibrated and for that reason are not easily available to the general public. None of the surveyed applications allow seamless integration with the Portuguese military maps for planning purposes.

Grade calculation and climb detection and classification are frequently supported for visualising or comparing performed activities. Nevertheless, grade calculation is often affected by inaccurate GPS data resulting in unrealistic information. On the other hand, the user cannot customise climb detection and classification to fit his level and special cases are not considered like multi-part climbs. None of the surveyed applications allow to automatically export relevant information about climbs to a GPS device.

Setting a constant pace based on a specified average speed is often supported by route planning applications. However, none of the reviewed applications allow setting a variable pace based on the terrain profile or the user's past activities. Adjusting the pace by percentage or by time/duration goals is also not possible.

Track simplification is often provided, mainly during export operations, in order to overcome GPS devices limitations on the number of track points that

may be displayed. It is not clear if track shape preservation is ever considered a simplification goal. Variable track point density is not supported.

3 Architecture

It was our purpose to design an application for visualising, editing and planning GPS-enabled outdoor activities. Therefore, the system's architecture must provide the foundation for the following requisites: a) multiple map providers support, including the Portuguese Military Survey maps; b) grade calculation and automatic climb detection and classification; c) activity pacing using multiple strategies; d) track simplification with shape preservation and higher track point density on climb sections; e) track editing capabilities, including joining and splitting tracks. Additionally, the application should support some non-functional requisites, such as: a) flexibility, allowing the application to be executed in multiple operating systems and in off-line mode; b) customisation, enabling the user to adapt the application's look and behaviour to his needs, including a multilingual interface; c) extensibility, allowing developers to enhance functionality and performance through extension mechanisms.

The domain model assumes a key role when designing an architecture as it determines the available information to work with, as well as the operations that may performed over that information. Thus, our main concern was to design a domain model that is both flexible to allow viewing, editing and planning activities; and extensible to accommodate additional features. Based on existing file formats, we have identified three core elements to our model: a) activities represent a performance, thereby they contain general information about the activity, aggregate data, positioning data, timing information, performance data, and environment measures; b) courses express a planned activity, which may be loaded into a GPS device and provide useful information while performing the activity; and c) waypoints provide useful information about landmarks, emergency services or sites of interest, thus aiding navigation.

By using the layering technique when designing the system's architecture we can reduce complexity and achieve better code organisation, as layers logically separate software components and provide isolation and independence between them. Moreover, layers allow us to substitute different parts of the system with alternative implementations, as well as run system's components in different platforms, thus contributing to increased flexibility and extensibility [7]. Taking into consideration both the prevailing best practices and the application's requisites, we have chosen to divide the application in three layers: a) the *presentation layer* responsible for displaying information to the user and dealing with user interaction; user's requests to perform operations are dispatched to the business layer; b) the *business layer* deals with the application's business logic; it essentially performs operations over the domain model; c) the *data source layer* is responsible for permanently storing the user's data in a database, while allowing the application to communicate with other systems and/or service providers. The three layers and their main components are depicted in figure 1.

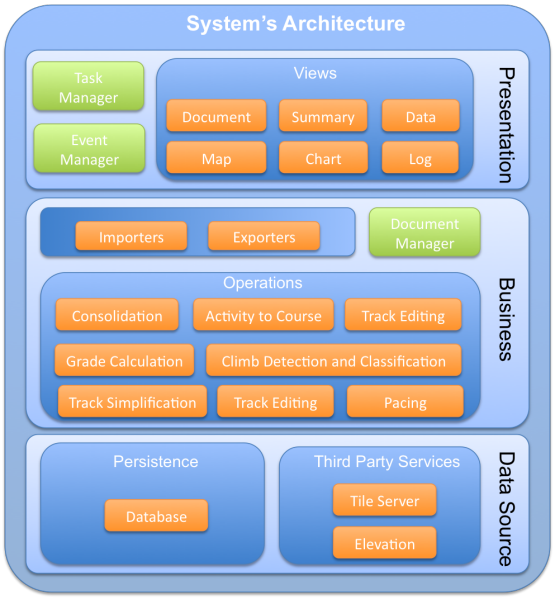

Figure 1. System's three layer architecture and main components.

The proposed architecture provides several extension points which can be summarised as follows: a) new attributes to domain model elements; b) advanced data views; c) additional map providers and layers; d) new operations and functionalities; e) third party services.

4 Implementation

The application was developed with Oracle's Java Platform, Standard Edition (SE), and it was designed to be portable, lightweight and self-contained. Dependencies on third-party products and services were kept to a minimum through the use of Standard Edition technologies whenever possible. Track It! is released under the GNU Public License (GPL) [8], version 3.0, in order to allow other students and developers to extend its functionality, while ensuring that it will continue to be freely available to the community.

The application's window has three areas. The centre pane contains the map view where most of the user interaction takes place. Because activities and courses are essentially visual and since route planning tasks are easier when displayed in context, it makes sense to devote this privileged space to mapping components. The left pane supports a navigation tree of opened documents and allows the user to easily select a course or an activity, as well as one of its segments, for instance. Some of the important operations are also available on this

tree view. The bottom of the left pane is dedicated to presenting summary information about the selected item. Finally, the bottom pane provides auxiliary views over the selected items, namely the chart view which graphically represents elevation, heart rate, cadence, among other; the data view, which displays detailed information about the selected item in a tabular layout; and the log view which allows the user to collect information about exceptions that occur or inspect the output of an operation. Figure 2 gives an overview of the application's main window, displaying a commute bike ride as an example.

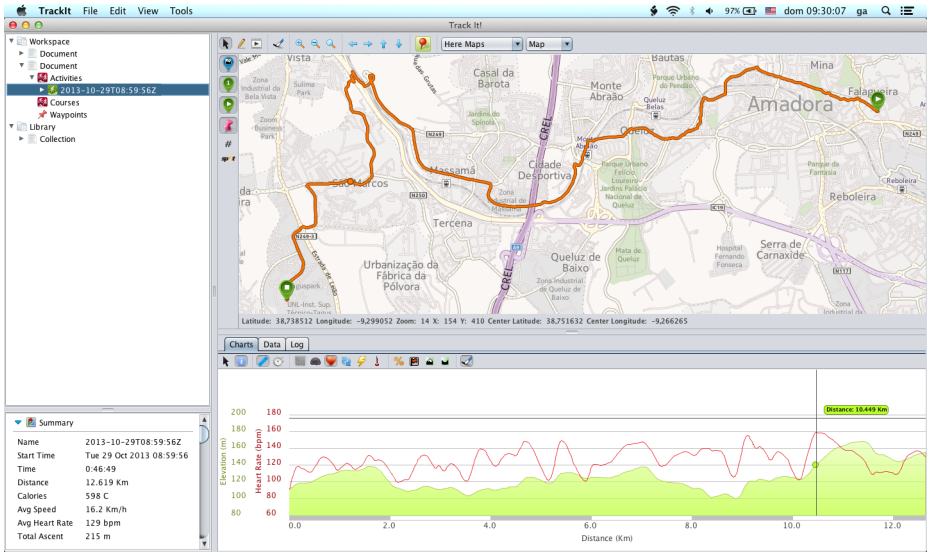

Figure 2. Track It! main window displaying a commute bike ride.

We decided to support the following six map providers: a) Google Maps; b) Bing Maps; c) Here Maps; d) OpenStreet maps; e) MapQuest Maps; and f) the Portuguese Military Survey maps.

Some core planning operations were included in the application. The list of available operations that may be performed over an item is obtained through an implementation of the factory design pattern [9]. The main supported operations may be summarised as follows:

- *Consolidation*: this operation ensures GPS data remains valid, consistent and complete; it performs data correction and validation, and calculates summary and missing data; filters are applied in order to remove outliers and high frequency variations due to GPS errors [10];
- *Grade calculation*: some of the most important contributions from this work rely on the knowledge about the steepness and direction of a given segment

or at specific location on a course; the steepness at any location within a course may be thought as the rate of change in altitude for a given distance; this quantity is also known as grade or slope; the higher the rate of change in altitude in relation to distance, the steeper the terrain, and higher will be the calculated grade or slope; the slope direction simply indicates if the terrain is ascending (climb) or descending (descent); the grade calculation operation determines the grade or slope at each location;
- *Climb detection, classification and annotation*: the detection operation divides a course into climb, descent and flat segments; the classification operation takes each one of these segments and categorizes them according to the specified criteria; finally, the annotation operation includes information about the categorized segments into the course;
- *Pacing*: this operation allows the user to set the reference pace for an activity, providing better predictions during the activity and contributing consistent and constant feedback about the performance in relation to what was planned; pace may be set to a constant speed, as a percentage of the actual time or distance, with a time or speed target, or calculated based on the terrain profile and the user's past history of activities;
- *Track simplification*: this operation allows the user to reduce the number of track points for a given track while maintaining its main features; track simplification has a significant impact on performance, not only when a course is displayed on a GPS device, but also when rendering and processing the course in the application; the main goals for this operation are to maintain the track's shape, to preserve reference points such as course points or lap boundaries; and to achieve a greater density of points in climbs, segments where accuracy is most important and speed is greatly reduced; a review of the main simplification algorithms is presented in [11] and [12];
- *Pauses removal*: this operation allows to remove pauses from a course thus contributing to more accurate estimates activity's moving time and speed.

5 Evaluation

Evaluation is an essential step in every system's design as it allows us to measure its effectiveness, efficiency and usability [13]. Moreover, evaluating a system often involves answering three fundamental questions: a) what is the purpose of the evaluation (why); b) what should be measured by the evaluation procedure and which tools and/or methodologies should be selected (how); c) in which moment should the evaluation take place (when).

In the case of the present study, evaluating the solution allowed us to acknowledge if the application meets the requirements defined in section 1, if the user is able to perform common planning tasks as advertised, and if the implemented algorithms are correct, efficient and produce the desired results. On the other hand, specific problems and limitations were identified, which are not only important for this work's conclusions, but also for proposing future research.

Usability tests are crucial whenever we need to collect data about the completeness of the system's functionalities, as well as the effectiveness and efficiency

with which an user can execute a set of proposed tasks. Moreover, this kind of testing frequently involves observing users interacting with the system, a technique which provides plenty of information about the system's strengths and limitations [14]. In this particular case, our intention in performing usability tests was to validate if the user was able to complete with success a series of test scenarios. We have created three test scenarios, as follows: a) Scenario 1: planning an activity based on a past activity; b) Scenario 2: planning an activity from scratch; and c) Scenario 3: Planning an activity by combining past courses and activities.

There are two important conclusions to draw from the results obtained. On the one hand, all of the test users were able to execute with success the tasks for the three proposed scenarios, although some of them needed advice from the evaluator, and in a few cases required extra help to conclude the scenario, especially users of the beginner's category. Nevertheless, it is often the case that some help is needed (e.g., information retrieved from the application's help system) whenever the subject is complex, the application is full-featured or the user is unfamiliar with the tasks at hand. In fact, some of these factors were reported informally by the users as they performed the test. On the other hand, it is interesting to note the learning effect. An user who struggled to convert an activity to a course in the first scenario showed almost no difficulty performing the same operation subsequently. This is a good indicator that once learned the application becomes easier to use.

Some of the core operations were also evaluated regarding their effectiveness, accuracy and performance, and the achieved results were markedly positive. The climb detection algorithm exhibited very accurate results concerning climb length and average grade. On all of the performed tests climb length was within the 1.0 km margin while the average grade did not fluctuate more than 0.6%, when compared with official data [15, 16]. The climb classification algorithm successfully categorised the tested climbs according to official data [15]. Finally, the track simplification algorithm tests demonstrated that the shape of a track is preserved during the simplification process, and that higher track point density is maintained in climb segments when compared to flat or descent segments.

6 Conclusions

We have created a dedicated GPS-enabled application which provides planning capabilities for outdoor sports and activities. We have also demonstrated that this application is not only useful for planning activities but it is also accurate, versatile and extensible to fulfil every user's needs. Notwithstanding planning being our primary goal, tools for visualising and analysing GPS data were also included.

Several requirements were taken into consideration when conceiving the application. Firstly, the proposed solution was designed to be multi-platform, flexible, customisable, extensible, small and to support off-line operation. This way, we have ensured that a planning session may be accomplished in a wide range

of situations or circumstances. Secondly, the application supports a myriad of editing tools for manipulating track points, course points, laps and segments, besides providing flexibility in ways courses may be created. Specifically, courses may be created from scratch or by manipulation of existing courses or activities. Thirdly, special attention was devoted to mapping support, specifically by providing a great variety of map providers and types, and by allowing flexibility and extensibility in order to support additional maps in the future. Moreover, we also achieved seamless integration of the Portuguese Military Survey Maps. Finally, we provide a collection of unique operations which deliver useful information while performing an activity. In particular:

- *Climb detection, classification and annotation*: this operation automatically detects climbs based on the terrain profile, classifies them according to the specified criteria and annotates information about climbs on courses to provide useful information while performing an activity;
- *Pacing*: this operation allows the user to set the pace to follow during an activity; pace may be specified as a percentage of a previous pace, manipulated to match a target time or speed, or automatically adjusted to a variable pace based on the terrain's profile and the user's past history of activities;
- *Pauses removal*: this operation allows removing pauses from a course, providing more accurate predictions regarding the activity's moving time;
- *Track simplification*: this operation simplifies the track of a course in order to improve performance without sacrificing the quality of the displayed data; it is worthy to note the ability of the algorithm to preserve the track's shape and to adjust track points density as a function of grade.

The proposed application was subject to usability tests in order to verify the effectiveness of the available operations and detect problems for future development. Results have shown that even inexperienced users are able to execute common planning tasks, provided some help is available.

Some of the core operations were also evaluated regarding their effectiveness, accuracy and performance, and the achieved results were markedly positive. Some of the most important conclusions are summarised below.

- *Climb detection algorithm*: tests with professional cycling races' data have shown that the algorithm exhibits very accurate results concerning climb length and average grade when compared to the official information about the climbs; on all of the performed tests climb length was within the 1.0 km margin while the average grade did not fluctuate more than 0.6%; small variations on climb starting points or multi-part climb detection were justified based on race organisation decisions and support for those hypothesis was provided; parameters proved sufficient to support the algorithm's flexibility;
- *Climb classification algorithm*: all of the tested climbs were successfully categorised according to official road books, which not only demonstrates that using statistical data on climb categorisation from previous races is an adequate predictor of the climb's difficulty, but also that the algorithm is flexible enough to adapt to specific categorisation requirements;

– *Track simplification algorithm*: test results demonstrated that the shape of a track is preserved during the simplification process, and that higher track point density is maintained in climb segments when compared to flat or descent segments; extreme simplification was employed to verify the algorithm's correctness and suggestions for future development were proposed, specifically on adapting the algorithm to extreme simplification conditions.

6.1 Suggestions for Future Developments

Despite the fact that the presented solution in this dissertation is fully functional and supports typical planning sessions' tasks, there are is still plenty of opportunities for improvements in the future. Specifically, we propose the following enhancements: a) the user interface could be simplified and streamlined in order to improve user experience, provide more flexibility and increase productivity; b) operations should be also applicable to segments and not exclusively to whole courses; c) profiles could be considered to provide customisation on the available operations. d) database support should be provided to allow the maintenance of a catalogue of activities and courses with searching capabilities; e) some visualisation enhancements could be included allowing performance comparisons on tracks and segments by the same user and/or different users; side by side comparisons should be provided for chart and data views; f) social support could be included, allowing the user to share and search for courses and activities, or to challenge other users on a specific course. g) the application could offer support to attach multimedia in order to enhance courses and activities.

References

[1] B. R. Toaster, "Bike route toaster." [Online]. Available: http://www.bikeroutetoaster.com/

[2] MapMyRide, "Map my ride: Cycling social network." [Online]. Available: http://www.mapmyride.com/

[3] GPSies, "GPSies — GPS, tracks, trails, tours, converter." [Online]. Available: http://www.gpsies.com/

[4] Strava, "Strava — running and cycling gps tracker, performance analytics, maps, clubs and competition." [Online]. Available: http://www.strava.com/

[5] S. Tracks, "Sport tracks: GPS-integrated workout logging software for windows PC." [Online]. Available: http://www.zonefivesoftware.com/sporttracks/

[6] Adze, "Use adze to edit gps data like a champ." [Online]. Available: http://www.http://kobotsw.com/

[7] M. Fowler, *Patterns of Enterprise Application Architecture*. Boston, MA, USA: Addison-Wesley Longman Publishing Co., Inc., 2002.

[8] "gnu general public license," free software foundation. [Online]. Available: http://www.gnu.org/licenses/gpl.html

[9] E. Gamma, R. Helm, R. Johnson, and J. Vlissides, *Design Patterns: Elements of Reusable Object-oriented Software*. Boston, MA, USA: Addison-Wesley Longman Publishing Co., Inc., 1995.

[10] MyTourBook, "Smoothing out gps and heart rate monitor data." [Online]. Available: http://mytourbook.sourceforge.net/mytourbook/files/mytourbook_smooth_11.8.2.pdf

[11] D. H. Douglas and T. K. Peucker, "Algorithms for the reduction of the number of points required to represent a digitized line for its caricature," *Cartographica: The International Journal for Geographic Information and Geovisualization*, vol. 10, no. 2, pp. 112–122, 1973.

[12] P. S. Heckbert and M. Garland, "Survey of polygonal surface simplification algorithms," 1995.

[13] H. Sharp, Y. Rogers, and J. Preece, *Interaction Design: Beyond Human-Computer Interaction*, 2nd ed. Wiley, Mar. 2007.

[14] A. Dix, J. Finlay, G. Abowd, and R. Beale, *Human-computer Interaction*. Upper Saddle River, NJ, USA: Prentice-Hall, Inc., 1997.

[15] A. S. Organization, *Livre de Route: Entrez dans la légend du Tour (100e Édition)*. Issy-Les-Moulineaux Cedex: A.S.O., 2013.

[16] ——, *Liège-Bastogne-Liège 2014 Edition*. Issy-Les-Moulineaux Cedex: A.S.O., 2014.